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RUNOFF PLOT DESIGN AND INSTALLATION FOR SOIL EROSION STUDIES

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Soil and Water Conservation Research Division
Agricultural Research Service
U. S. DEPARTMENT OF AGRICULTURE

In cooperation with the Minnesota Agricultural Experiment Station

RUNOFF PLOT DESIGN AND INSTALLATION FOR SOIL EROSION STUDIES

Calvin K. Mutchler [1] [2]

INTRODUCTION

Inquiries are often received concerning procedures for initiating runoff plots and criteria for plot design. This publication is designed to meet that need by describing a logical step-by-step procedure for establishing runoff plots.

Fractional-acre runoff plots have been used in the United States since 1917 to measure soil and water losses due to rainfall. The research objective was generally to evaluate erosion; hence, little has been published on equipment used. Also, the high cost of establishing and operating erosion stations has contributed to the small number of installations and to wide geographical separation of the stations.

Most erosion stations have been designed and built by groups interested in the specific problem area involved. Together with the large distances and lengths of time involved between setup of projects, this has resulted in a great variety of equipment designs. Many of the differences in designs were those occurring whenever two people do similar jobs. Others were caused by different performance requirements--such as resistance to the effects of frost-heaving in the North, which is of little concern in the South.

Although location of the plot area depends primarily on the research objectives, some site requirements are essential to satisfactory erosion measurements. A method is suggested to aid location and selection of the area.

The section on design criteria reports rules and methods on equipment design that are not encountered frequently by engineers doing erosion work. Every installation in use today is unique. Local conditions may require deviations from that shown, but the attempt is to illustrate one solution. The equipment is based on the use of the multislot divisor, which is one of the best sampling units we have today for quantitative measurements of soil loss and runoff.

Runoff plot equipment using the multislot divisor is shown in figure 1. This installation is located at Morris, Minn. and is insulated for winter snow-melt measurement. In figure 2 is a picture of an installation using the rotating-slot sampler, which is sometimes used instead of the multislot divisor for soil loss measurement.

There are as many ways to install runoff equipment as there are types of equipment. Although the antisedimentation device for the H flume is still somewhat in the development stage, it is needed so badly for heavy sediment conditions that it warrants description.

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[1] Agricultural Engineer, Corn Belt Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, at Morris, Minn.

[2] The author wishes to express his appreciation for the advice and information received from some of the Agricultural Research Service personnel presently engaged in erosion plot work: Orville E. Hays, LaCrosse, Wis.; George R. Free, Ithaca, N.Y.; R. E. Burwell, Morris, Minn.; Coy W. Doty, Holly Springs, Miss.; A. P. Barnett and John R. Carreker, Athens, Ga.; and Fred D. Whitaker, Columbia, Mo. Their fine cooperation is greatly appreciated. Thanks are due also to Donald A. Parsons, University, Miss., for his letters and material describing the development and history of the H flumes and multislot divisor runoff samplers, and to D. D. Smith, Beltsville, Md., for making available his files on runoff plot equipment.

Figure 1.--Runoff plot installation at Morris, Minn., that illustrates use of multislot divisor. All the equipment is insulated, except the second aliquot tank, to allow snow-melt runoff measurement.

Figure 2.--Runoff plot installation with a flume and rotating-slot sampler at Holly Springs, Miss. A one-half percent sample of the runoff is taken by the rotating-slot sampler and conveyed to a storage tank, which is not shown.

NOTATION

The following symbols are used in the equations that are given in this publication:

A = area in feet^2.
b = width of channel in feet.
C_d = coefficient of discharge.
D = hydraulic depth in feet.
d_c = critical depth in feet.
d_o = pipe diameter in feet.
G = freeboard in feet.
g = acceleration of gravity in feet/second^2.
H = total head above centerline of pipe entrance in feet.
M = total depth of section in feet.
n = Manning's coefficient.
Q = discharge in feet^3/second.
Q_c = critical discharge in feet^3/second.
R = hydraulic radius in feet.
S_c = critical slope in feet/feet.
$S_{0.2}$ = slope at 20 percent maximum flow in feet/feet.
T = width of free surface in feet.
V = velocity in feet/second.
V_c = critical velocity in feet/second.

SELECTION OF AREA

Geographic Area and Soil Type

The objectives of erosion study projects in the past have generally included a crop or management comparison and an evaluation of soil and water losses as influenced by the climate and soil. However, as the use of plot-size rainfall simulators, such as the rainulator (3),[3] becomes more widespread, most runoff plots under natural rainfall will be used primarily to evaluate erosion as influenced by the climatic and soil conditions of a particular geographic area. Therefore, the new plots used for climate evaluation are located on a major soil type and on a prevailing slope.

If the erosion experiment objective is to compare erosion effects of cropping or management treatments, the plots must accommodate statistical comparison. All plots in that type of experiment should have comparable slopes, soils, and land use history, i.e., the variance due to variables other than those being studied should be minimized.

General Topographic Considerations

Once the general geographic location and soil type have been selected, a specific area must be chosen to accommodate the runoff plots. At this stage, a decision must be made as to number of plots, slope length and percent, aspect, and area required for plot installation.

[3] Underscored numbers in parentheses refer to Literature Cited, p. 22.

The majority of the earlier plots were 72.6 feet long. With this length, widths in multiples of 6 feet give multiples of 1/100 acre in area. These sizes were widely used in the past for convenience in making calculations and were suitable for crops planted in rows across the slope. Slope length is an independent variable that is easily held constant. The 72.6-foot length for new plots has the advantage of allowing more direct comparison with old data.

It is now recognized, however, that contour field management cannot be simulated by across-slope managed runoff plots because of complete balking within small plots and little concentration of row water. Therefore, most plots now are tilled and seeded up-and-down hill, and quantitative data are adjusted for effectiveness of contour-farming. With this procedure, multiples of row width make convenient plot widths; for instance, 4-row plots are often used for corn.

Plot width has little relation to soil loss per unit area on the up-and-down hill plots. Borders should be planted to the same crop as is on the plot. A minimum width of two 40-inch corn rows is recommended. When a tractor with spread front wheels is used, the middle two rows in the plot are cultivated first, then one row inside and one row outside the plot are cultivated. This procedure allows cultivating without removing the plot boundaries but also requires three border rows. Use of a tricycle tractor allows two border rows but requires bringing together the rear wheels or removing the plot boundaries.

Percent slope is usually limited by the soil type selected. However, erosion effects due to treatments are more pronounced on the steeper slopes. Therefore, if the desired soils can be found on 3- to 8-percent slopes, for example, selection of an area in the 5- to 8-percent range is desirable.

Direction of slope exposure and prevailing wind direction are thought to be factors affecting erosion. However, their effects have not been quantitatively evaluated. When applied treatments are to be compared, location of all plots in the same general direction of exposure is recommended. When climatic conditions only are being evaluated, randomization over all directions of slope may be preferable. Practical considerations and area limitations usually dictate the location of plots on a common slope.

Considerable area is required below the plots for the measuring equipment. Although the main requirement is that of head, excavation can often be reduced by placing runoff collecting tanks farther down the slope. Since most erosion experiments under natural rainfall must run for 15 to 20 years, long-term maintenance and ease of operation should receive careful consideration when planning the installation.

After the most desirable plot dimensions as outlined above are established, a reconnaissance of the problem area can be made to select an area which includes the required slopes and soils.

Topographic Data Required

For use in preliminary planning, a topographic map of the selected area with a contour interval of 5 feet should be made. The interval can be split for parts having less than 3 percent slope. A 100-foot grid system and a surveyor's level are convenient for making the overall map. Aids and assistants can do practically all the fieldwork and some of the mapping with very little professional supervision. A soils map should be made and overlayed on the topographic map. Stakes used for the grid system make a good reference system for the soil surveyor.

Possible plot sites can be selected by examining the topographic and soils map. These sites should be surveyed again on a smaller grid spacing, starting from a base line laid out on a contour. A 10-foot grid is good for this detailed survey. From this map, the plot can be accurately located as to average slope, irregularities and detailed soils analysis. A good guide is to tolerate no more than plus or minus 2/10 foot irregularity from the average plane surface. Some smoothing may be done but only with the counsel of a soils man experienced in soil erosion work.

Summary of Area Requirements

A runoff area may be selected in the following manner: Obtain a tract of land having the desired slopes and soil type. Decide on size, shape, and number of plots, as related to the land management and experimental objective. Select a desired percent slope from the upper half of the slope range for the soil type. Make a 5-foot contour map of the entire tract and overlay it with a soils map. Select possible plot sites from this map considering slope, soil and space for measuring equipment. Decide on final plot locations from a large scale topographic map of the plot site and from a final detailed soil survey.

EQUIPMENT DESIGN CRITERIA

Erosion plot equipment must be adequate to collect runoff and soil loss from the plot and to store all or a part for measurement and analysis. Therefore, an estimate must be made of maximum runoff and soil loss, both rate and amount.

Runoff Estimates

Plot size is determined by the extent of the experimental objectives and the proposed cropping management. If the size of the area contributing to runoff is known, maximum runoff rate and amount can be estimated by the use of long-term weather records (7, 8). Use of a 100-year frequency storm is recommended. Most organizations can service the plots daily so that 24 hours can be used as a storm-duration figure to calculate maximum storage amounts. Since short-duration intensities are highest, an estimate must be made for "time of concentration," which is the time required for all parts of the plot area to contribute to the maximum runoff rate measured at the bottom of the plot. This becomes a difficult procedure for runoff plots under any set of conditions (4), so it is best to make a practical estimate. Since 5 minutes is the smallest time-interval generally used in calculating maximum rainfall intensities, the 5-minute duration intensity should be used to estimate the size of rate-measuring equipment needed for bare and clean-tilled plots. Although runoff rarely equals 100 percent of the rainfall, it is probably safest to use 100 percent of the 24-hour-duration rainfall amount for storage capacity, and 100 percent of the 5-minute-duration rainfall intensity for estimating maximum runoff rate. Estimates of runoff rates and amounts may be decreased in proportion to the amount of cover and conservation practices used in the experimental treatment.

Soil Loss Estimates

An estimate of soil loss is needed to get a design volume for storage. As much as 50 tons per acre have washed off a bare plot in a single storm of about 8 inches of rain. This figure can be adjusted for the climatic conditions of the area. Other considerations, as will be discussed later under equipment for storage units, allow this estimate to be relatively loose.

Sediment Conveyance

Since conveyance of runoff and sediment is always involved in erosion plot work, design figures are needed to specify minimum slopes of round pipes and rectangular channels that will move the sediment expected.

The dominant principle in sediment transport is to design the conveyance for a minimum velocity of 2 feet per second at about 20 percent of the largest flow expected. This will insure nonsilting velocities throughout most of the range of flows encountered. Also, because of the usual topographic requirement of elevation head economy, an open channel design should be used.

If the above requirement for minimum velocity is used, any channel must be placed on a supercritical slope. Thus, the design problem resolves into a calculation of capacity governed by entrance conditions and slope requirements to maintain a minimum velocity. Since the flow goes through critical depth, the channel depth at entrance must equal critical depth plus half the hydraulic depth plus freeboard in the case of an open conduit.

For a rectangular channel, the total depth of section ($\underline{M}$) is

$$\underline{M} = \underline{d_c} + \frac{\underline{D}}{2} + \underline{G} \tag{1}$$

where $\underline{D}$ = hydraulic depth $= \frac{\underline{A}}{\underline{T}} \left[= \underline{d_c} \text{ for a rectangular section} \right]$. Thus,

$$\underline{M} = \frac{3}{2}\underline{d_c} + \underline{G} \tag{2}$$

Critical depth is dependent solely on flow rate. Therefore, the estimate of runoff rate is used to calculate critical depth from the equation

$$\underline{d_c} = \left(\frac{\underline{Q}^2}{\underline{b}^2 \underline{g}} \right)^{1/3}$$ where $\underline{Q}$ is flow rate and $\underline{b}$ is channel width.

Select a value for freeboard ($\underline{G}$) of approximately 10 percent water depth. Thus,

$$\underline{G} = \frac{1}{10}\left(\underline{d_c} + \frac{\underline{D}}{2} \right)$$

and find $\underline{M}$ with the aid of equation 1. Note that this $\underline{M}$ is used to determine the depth of the channel and to determine the minimum collector depth to prevent plot ponding.

For circular conduit, the pipe must have enough capacity to insure that the headwater is never higher than the pipe inlet. (Note that this fixes the maximum depth of water and allows design of equipment upstream of the conveyance.) If we use these criteria,

$$\underline{d_o} = \underline{d_c} + \frac{\underline{D}}{2} = \underline{d_c} + \frac{\underline{A}}{2\underline{T}} \tag{3}$$

This is an implicit function in $\underline{d_c}$ and is best solved by approximation by the use of a set of tables giving geometric elements for circular sections.

As a result, $\underline{d_c} = 0.6887\ \underline{d_o}$. Using this, we can write the following formulas:

$$\underline{Q_c} = 2.58\ \underline{d_o}^{5/2} \tag{4}$$

$$\underline{S_c} = 46.3\ \frac{\underline{n}^2}{\underline{d_o}^{1/3}} \tag{5}$$

Slope is determined by using the requirements of 2 feet per second at 20 percent maximum flow in Manning's formula. Then the minimum slope is the larger of the 2 slopes, critical slope or slope at 20 percent flow.

$$\underline{S}_{0.2} = \left[\frac{\underline{Q}_{0.2}\, \underline{n}}{1.49\, \underline{AR}^{2/3}} \right]^2 \tag{6}$$

where

$$\underline{A} = \frac{\underline{Q}_{0.2}}{\underline{V}} = \frac{0.2\underline{Q}}{2} \tag{7}$$

and

$$\underline{S}_{min} = \max \begin{cases} \underline{S}_{0.2} \\ \underline{S}_{\underline{c}} \end{cases} \tag{8}$$

The following example gives the steps for calculation of pipe size and slope.

Given: Maximum runoff rate estimate - $\underline{Q} = 0.2$ c.f.s.

$$\underline{V}_{min} = 2 \text{ f.p.s.}$$

$$\text{Manning's } \underline{n} = 0.0149$$

From equation 4, $\underline{d}_{\underline{o}} = \left(\frac{0.2}{2.58} \right)^{2/5} = 0.36$

Now, $4/12 < \underline{d}_{\underline{o}} = 0.36 < 5/12$

So, use 5-inch-diameter pipe. Substitute data in equation 5

$$\underline{S}_{\underline{c}} = 46.3 \frac{(0.149)^2}{(5/12)^{1/3}} = 0.0138$$

From equations 6 and 7, use $\underline{V}_{min} = 2$ and the tables of geometrical elements for circular channel sections

$$\underline{S}_{0.2} = \left(\frac{0.04 \times 0.0149}{1.49 \times 0.002715} \right)^2 = 0.0217$$

Therefore,

$$\underline{S}_{min} = \underline{S}_{0.2} = 2.17 \text{ percent} > \underline{S}_{\underline{c}}$$

Design of channels for other shapes can be made if the same design criteria as outlined above are used.

Summary of Design Criteria

To estimate total runoff and soil loss storage required, use 100 percent of the 24-hour-duration rainfall amount expected once in 100 years. Maximum runoff rate should be estimated by using 100 percent of the 5-minute-duration rainfall intensity expected once in 100 years. Storage should be allowed for about 50 tons per acre soil loss.

Conveyance pipes or channels should be designed to carry the flow under open channel conditions at supercritical velocities. Channel size is determined by the assumption that the design flow equals critical flow of the channel shape chosen. Minimum slope is determined either by the figure obtained for critical flow at the entrance or by the figure that gives 2 feet per second velocity at 20 percent flow, whichever is the larger.

EQUIPMENT

Outlined in general, equipment needs for a runoff plot are (see figs. 3 and 4):

1. Boundaries around the plot to define the measured area.
2. Collecting equipment to catch and concentrate runoff from the plot.
3. Conveyance equipment to carry runoff to a sampling unit.
4. Sampling unit to aliquot the runoff and soil loss into manageable quantities.
5. Storage tanks to hold aliquot portions of runoff and soil loss for analysis.

Other equipment is sometimes desired. It is helpful in analysis to have a runoff hydrograph. Hence, a rate-measuring flume is placed between the collector unit and the sampling unit. Special heating equipment is needed if snow-melt runoff is evaluated.

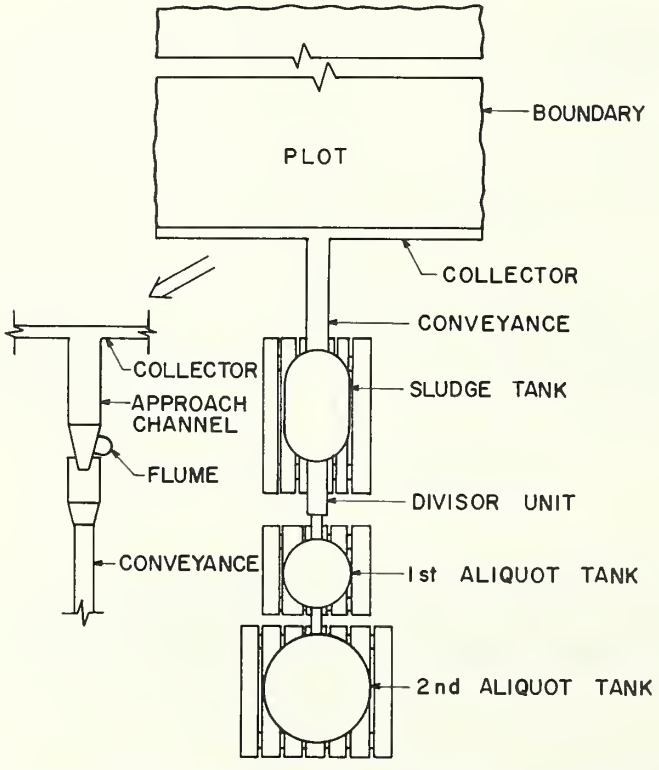


Figure 3.--Typical plan of runoff plot equipment.

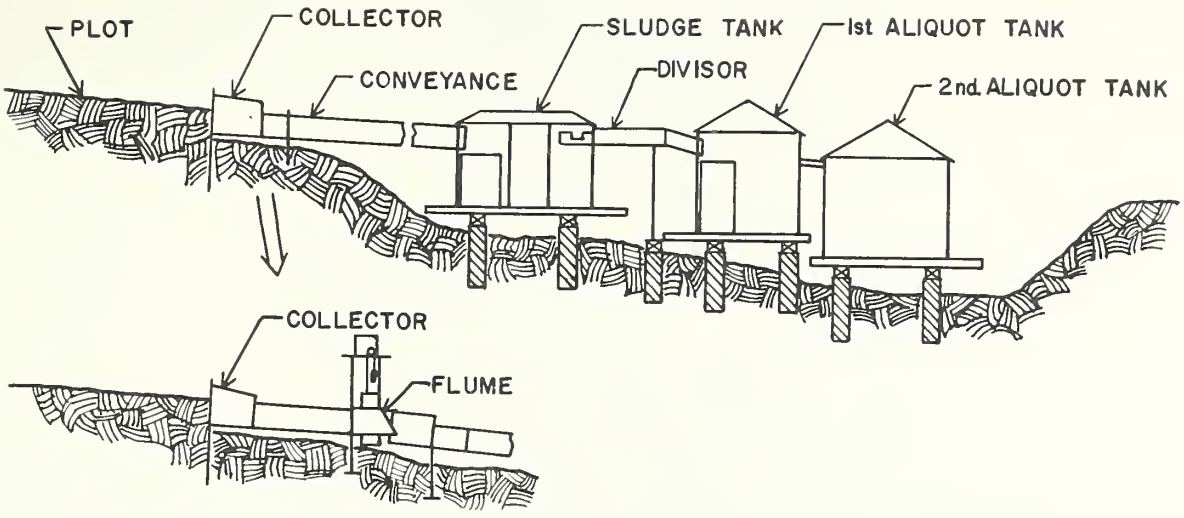


Figure 4.--Typical profile through the centerline of a set of runoff equipment.

Plot Boundaries

Several methods have been used to define runoff plot areas. Dikes in combination with terrace channels have been used generally on plots larger than one-fourth acre. Strips of 16-gage galvanized steel approximately 9 inches high by 6 to 12 feet long, with corrugations running across the small dimension, make excellent boundaries for cultivated plots. These are comparatively easy to install and maintain. Where the boundaries are permanently installed, smooth galvanized steel strips, 14-gage are preferred.

Runoff Collector

Collecting equipment of many different designs and materials has been used on the runoff stations throughout the United States. The collector generally acts as a weir across the bottom of the plot and a channel for runoff to the sampling unit. Sheet-metal construction is preferred to concrete, because the collector elevation must be adjusted to the level of the plot as erosion occurs. An endplate made of heavy gage galvanized steel blocks off the plot end and furnishes a stable attachment for the trough of the collector. The endplate should extend at least 8 inches below the collector trough.

The collector trough acts as a channel for the runoff material. This trough (together with the endplate) is designed to reach across the entire width of narrow plots. For plots wider than 14 feet, it is best to concentrate the runoff before collecting it, as shown in figure 5.

The major elements of collector trough design are depth, width, and bottom slope (fig. 6). Design depth can be figured two ways, depending on whether a measuring flume is used or whether runoff is conducted directly to the sludge tank. If a flume is used, depth of the collector is controlled by the size of the approach channel required by the flume. In other words, the design is started by choosing the type and size flume necessary to handle maximum runoff. Thus, depth of the collector is equal to depth of the flume plus about 10 percent freeboard.

When only a conveyance pipe is used (no rate measurement), the collector depth is based on the pipe size needed to carry the runoff load (see also p. 5).

After the collector depth is calculated as discussed above, a freeboard of approximately 0.4 foot is added to the collector trough. This freeboard is needed primarily to form a notch across the plot end and may be changed to suit local design requirements.

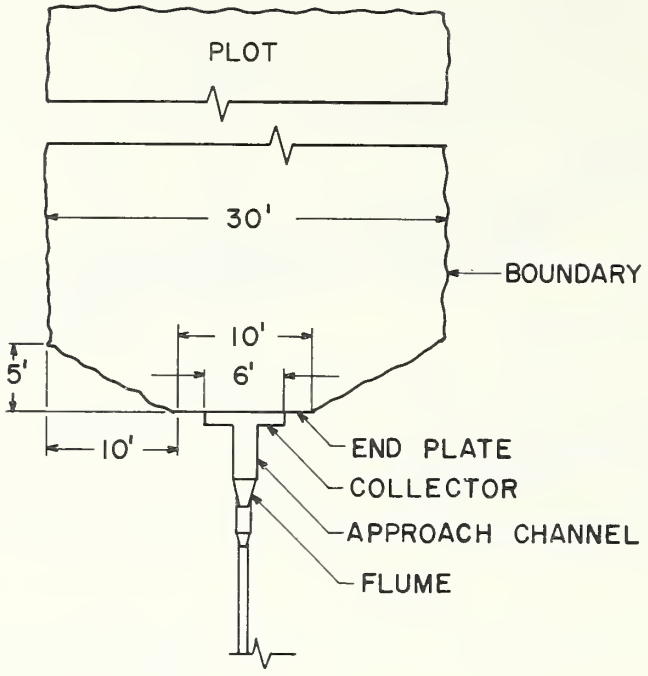
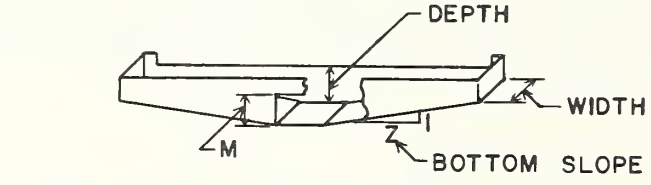


Figure 5.--Runoff collector for a 30-foot wide plot.



NOTES: 1. M IS EQUAL TO HT. OF APPROACH OR CONVEYANCE CHANNEL.
2. DEPTH IS EQUAL TO M OF NOTE 1.

Figure 6.--Critical dimensions for the collector trough.

Width of the trough, within limits, is largely a matter of preference. It should be narrow enough to form an efficient channel but wide enough to allow a worker to clean it easily--about 6 to 10 inches or an amount equal to H, the depth of the flume. Bottom slope is usually predetermined by the overall length of the trough and the required depth. However, a good figure to use is a 5 percent minimum slope.

Screens should always be used on the collector troughs to keep trash out of the system. Screen of 1/2- or 1-inch mesh works well and can be laid over the collector trough on strap iron braces as shown in figure 7.

Measuring Flumes

It is often desirable to have a runoff hydrograph from erosion experiments. The H and HS flumes (2) are recommended as rate-measuring devices. Some of the larger plots and small

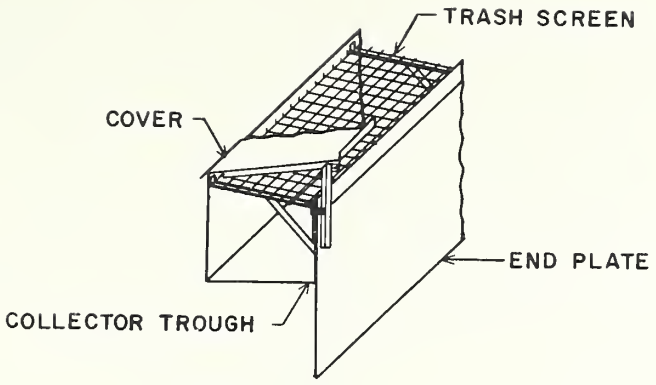


Figure 7.--Section through collector.

watersheds would require large H flumes; however, designs for those large installations should be prepared with on-site information and are not discussed here.

The H flumes were developed as a device that would be free from trash difficulties, capable of passing soil, and, with small width at the bottom, measure the small sustained flows accurately. Flow through these flumes is based on the formula:

$$Q = \left[(2g)^{1/2}\right]\left[\frac{2}{3} C_1 b h^{3/2} + \frac{8}{15}\frac{C_2}{N} h^{5/2}\right] \quad (9)$$

The first term of the sum within the brackets applies to the flow through a rectangular notch of width b and water depth h. The second term applies to flow through a V notch of side slope N on 1 and water depth h. The projected area of the H flume opening has these two elements of area. The term g is the acceleration due to gravity; C_1 and C_2 are coefficients.

Parsons used the above equation and data of DeFabritis and prepared rating tables. These tables together with proportions and plans for H and HS flumes are reproduced on pages 22 to 34 of the "Field Manual for Research in Agricultural Hydrology" (2).

All flumes should be individually rated. This applies especially to the smaller HS flumes. A device to combat the problem of measurement inaccuracy due to sediment deposition in the flume is being developed by the Agricultural Research Service (see next section).

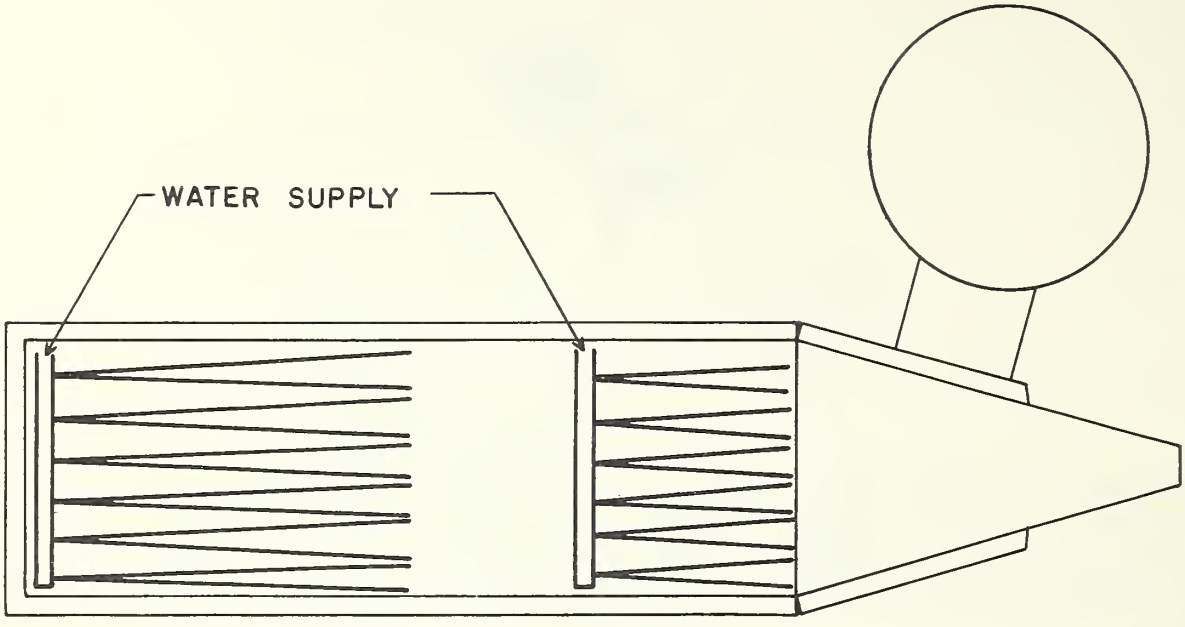
Antisedimentation Device

Small H and HS flumes measure runoff very accurately when the silt load is low. However, high silt or sand content causes deposition in the flume itself. This alters the flow cross-section and erratic flow measurement results. This has been a perplexing problem for many years.

While working on the rainulator (a rainfall simulator), Lee F. Hermsmeier, a research engineer at the Morris Station, developed an antisedimentation device for a 0.6 HS flume adaptation used with the rainulator (1). Although the device has not been adapted to the regular H and HS flume installation, the method seems quite adaptable.

The idea essentially is to maintain a highly turbulent base flow through the approach channel and flume. This is done with two water sprays--one striking the rear line of the flume floor at a 45° angle, the other striking the approach section floor about in the middle at an angle of approximately 7°. Adjustment of the first nozzle is quite critical, since it is near the measuring section; positioning of the second nozzle, within limits, has little effect on flume calibration.

The essential elements of the antisedimentation device are shown in figure 8. Water under pressure is required to operate the nozzles. On natural runoff plots, this could be controlled



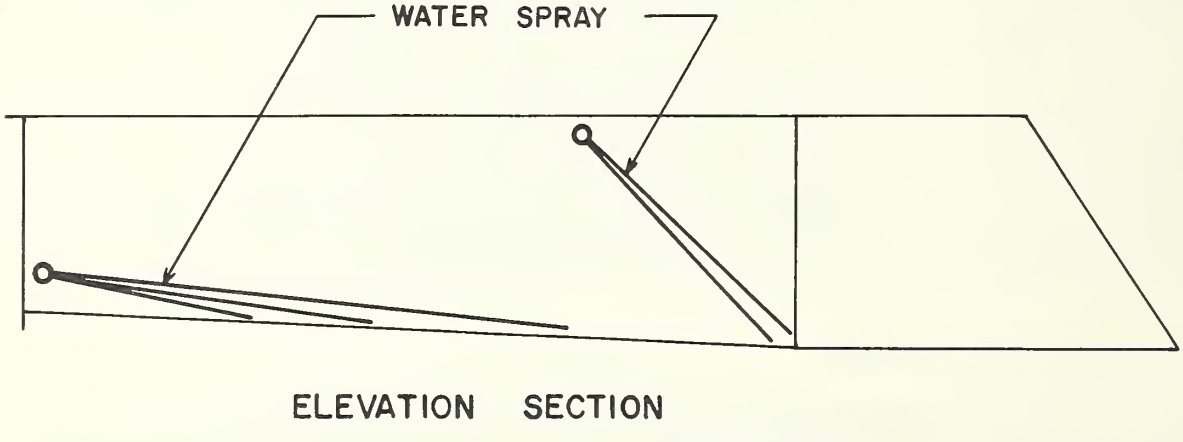


Figure 8.--Antisedimentation device for flumes.

with a solenoid valve activated by the float on the water stage recorder. Measurements of low flows by the device have been quite inaccurate; the writer suggests using a base flow to be turned on the same time as the spray nozzles. Thus, the flume would measure runoff only in the reliable portion of the rating curve. Use of the antisedimentation device requires a different rating curve from that shown for the regular HS flume.

Aliquot Sampling

Runoff from large storms invariably is too voluminous to sample directly for soil loss. Therefore, a method of aliquoting is used. This is a difficult problem, since soil and water do not have the same density and hence a mixture is rarely homogeneous. Various devices have

been used for sampling, the most notable being the Coshocton-type rotating-slot sampler as described by Parsons (5, 6) and the Geib multislot divisor (see figs. 1 and 2). The advantage of the Coshocton-type sampler is that a small amount of sampling labor is required, due to the small (1 percent for one of 1/3 c.f.s. capacity) aliquot extracted from the total runoff. The major objection to the Coshocton-type sampler is inaccuracy due to silting of the H flume, which is an integral part of the sampler. Although use of the multislot divisor requires a large amount of labor, it is a near-precision device that is quite reliable and time proven and, hence, is still preferred by many in erosion research. Possibly the best reason for accuracy of the multislot divisor is the use of a sludge tank, thus requiring division only of water and suspended sediment.

Multislot Divisor

The multislot divisor, often called the Geib divisor after its originator, H. V. Geib, is based on the premise of a uniform horizontal flow velocity throughout the head variations. Thus, flow through the slots of the multislot divisor (fig. 9) is divided into equal parts, and various-sized aliquots may be had by varying the number of slots. Extensive tests were run on these divisors by the Soil Conservation Service at the National Bureau of Standards. Precision of the device is illustrated by the calibration curve of a 5-slot divisor in figure 10. With careful construction and installation, the divisor ratio should be accurate to about 1 percent for a runoff period.

As mentioned before, one of the reasons for the great success of the multislot divisor is the use of a sludge tank. The divisor is required to handle only a suspended silt load, since all the heavier material drops out in the sludge tank. An entrance arrangement to the divisor is used to insure suspended load mixing (see fig. 9).

Detail plans for the multislot divisor are included in the Appendix. The construction details can be changed as long as the design principles are maintained. These principles are (1) slot similarity of size, shape, and position; (2) approach channel cross-section dimensions; and, (3) approach flow smoothness, e.g., no sharp protruding edges to disturb the flow. The

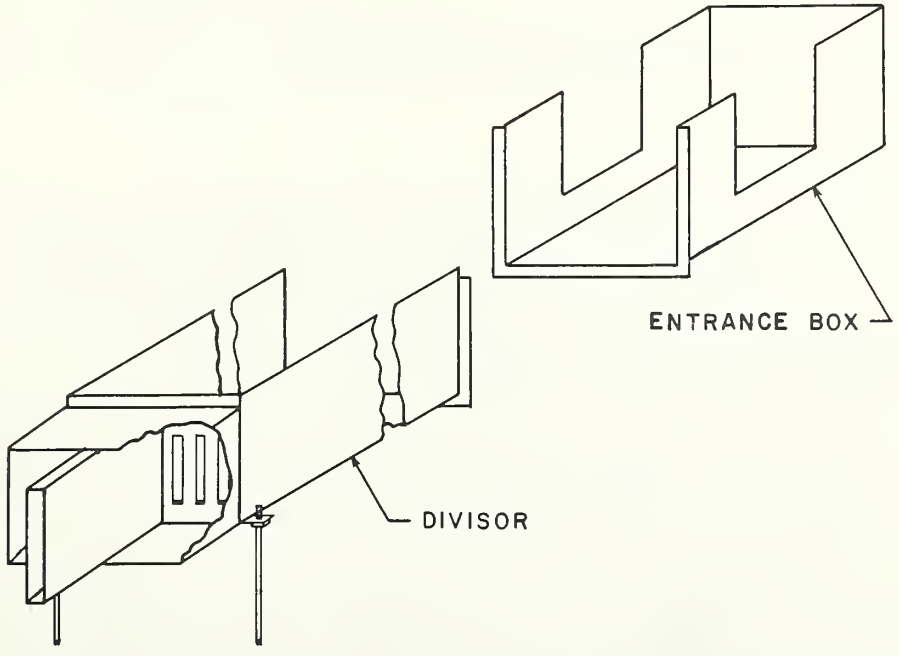


Figure 9.--Multislot divisor.

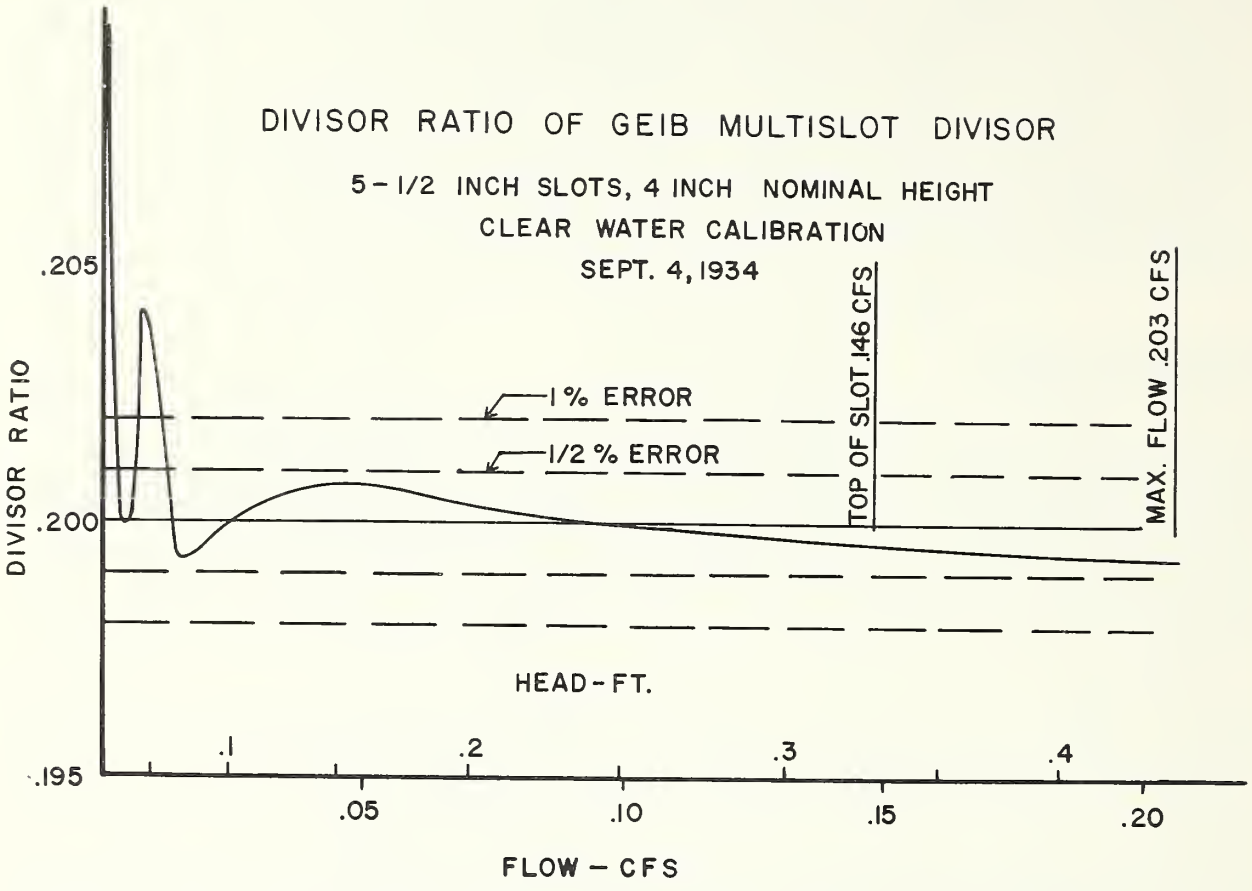


Figure 10.--Calibration curve of a divisor unit.

contractor who has equipment for punching the slot plate can achieve slot similarity much easier than one who must saw and shape to the required tolerance.

Storage Units

Tanks are used to store all the sludge and the aliquot of the soil loss-runoff mixture. Oval end stock water tanks make good sludge tanks and are commercially available in 2-foot height. Some companies will make tanks 29 or 30 inches high on special order, which are preferable to a 2-foot height because of the higher storage capacity. Round tanks are recommended for aliquot storage; these usually have to be custom made.

The sludge tank unit has two major functions: (1) To retain all the heavy soil material and pass only a suspended sediment mixture to the divisor unit; and (2) to store sludge which will make up the bulk of the soil loss from the runoff plot. Turbulence in the sludge tank due to high entrance velocities from the runoff plot is reduced by placing two screens across the flow through the sludge tank, thus increasing deposition. The screens also keep trash from clogging up the divisor. Details on the screens are shown in figure 11. The screens do not extend to the tank bottom and freeboard is allowed at the top. This is done to insure flow even though the screens become filled with trash. Floor space between the tank inlet and first screen is left for a can to catch low flows, so that the entire tank need not be cleaned after every rain shower.

The 50-ton-per-acre maximum soil loss figure discussed under design criteria is used to calculate storage capacity of the sludge tank. A cubic foot of soil weighs from 60 to 100 pounds,

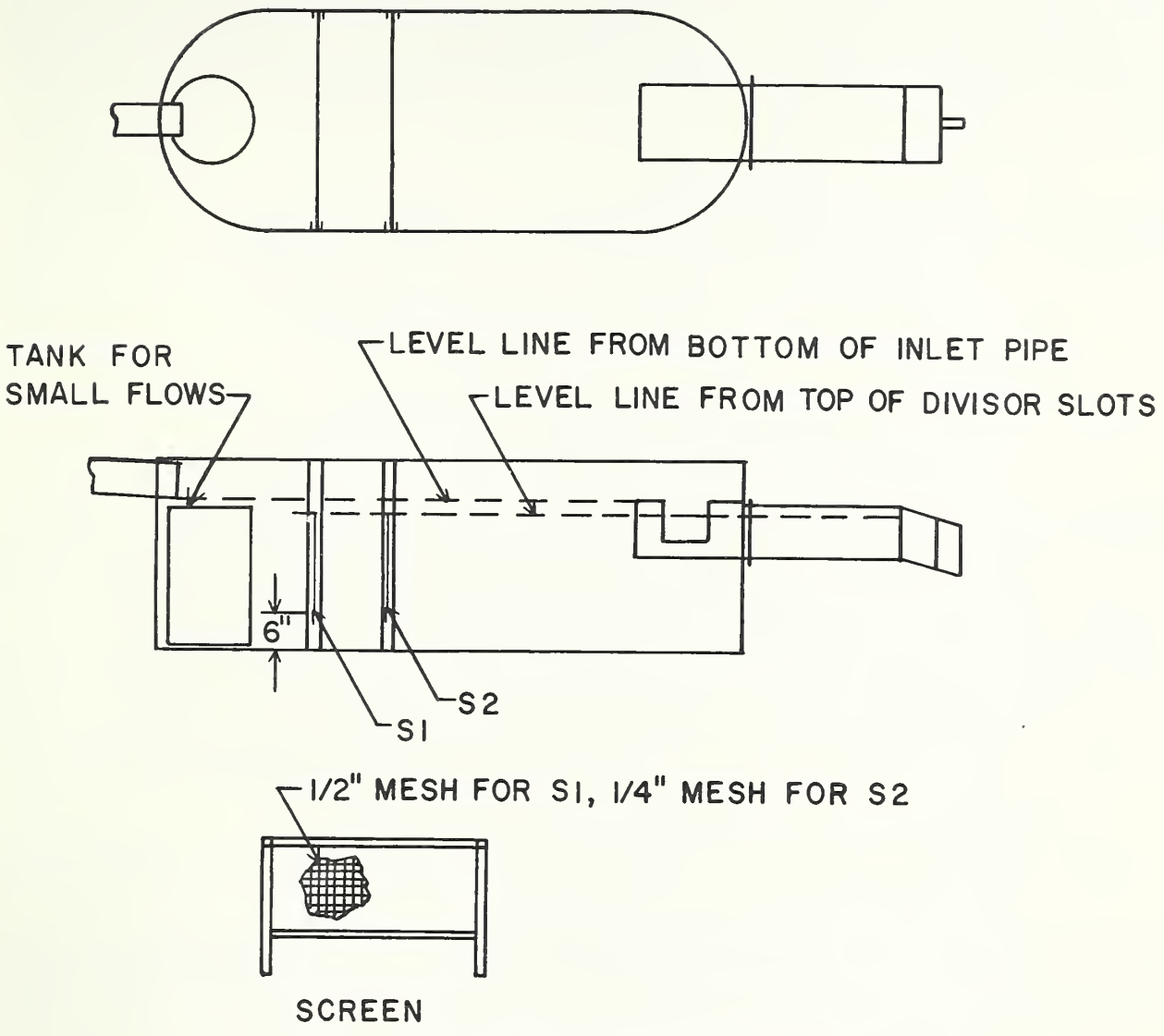


Figure 11.--Sludge tank and accessories.

so storage space can be calculated with the 60-pound conversion factor unless a closer figure is known. At design capacity, sludge should be no higher than the bottom of the entrance to the divisor unit. Note, however, that the result of underestimating soil loss merely increases the amount of sediment passing through the divisor unit.

The aliquot tank has no function other than storage. As in the sludge tank, a can is set under the inlet to catch small flows. If the expected runoff requires an overly large aliquot tank, a second tank may be used to catch overflow. For very high total catches, another divisor may be used between the aliquot tanks.

The tanks should be easy to clean. Therefore, the screens should be removable, and the tank bottoms should slope toward a drain or be fitted with sumps.

Snow Melt Sampling

Measurement of snow melt on runoff plots presents the possibility of ice in the measuring and storage equipment. All the equipment has to be heated. The conveyance parts can be warmed

with heating tape instrumented to operate at air temperatures between 25° and 35° F. Stock tank heaters set to operate under 35° will prevent freezing in the storage tanks. The sketch in figure 12 shows the essential equipment and controls for heating the plot equipment. Figure 1 shows an installation at Morris, Minn., prepared for winter measurements.

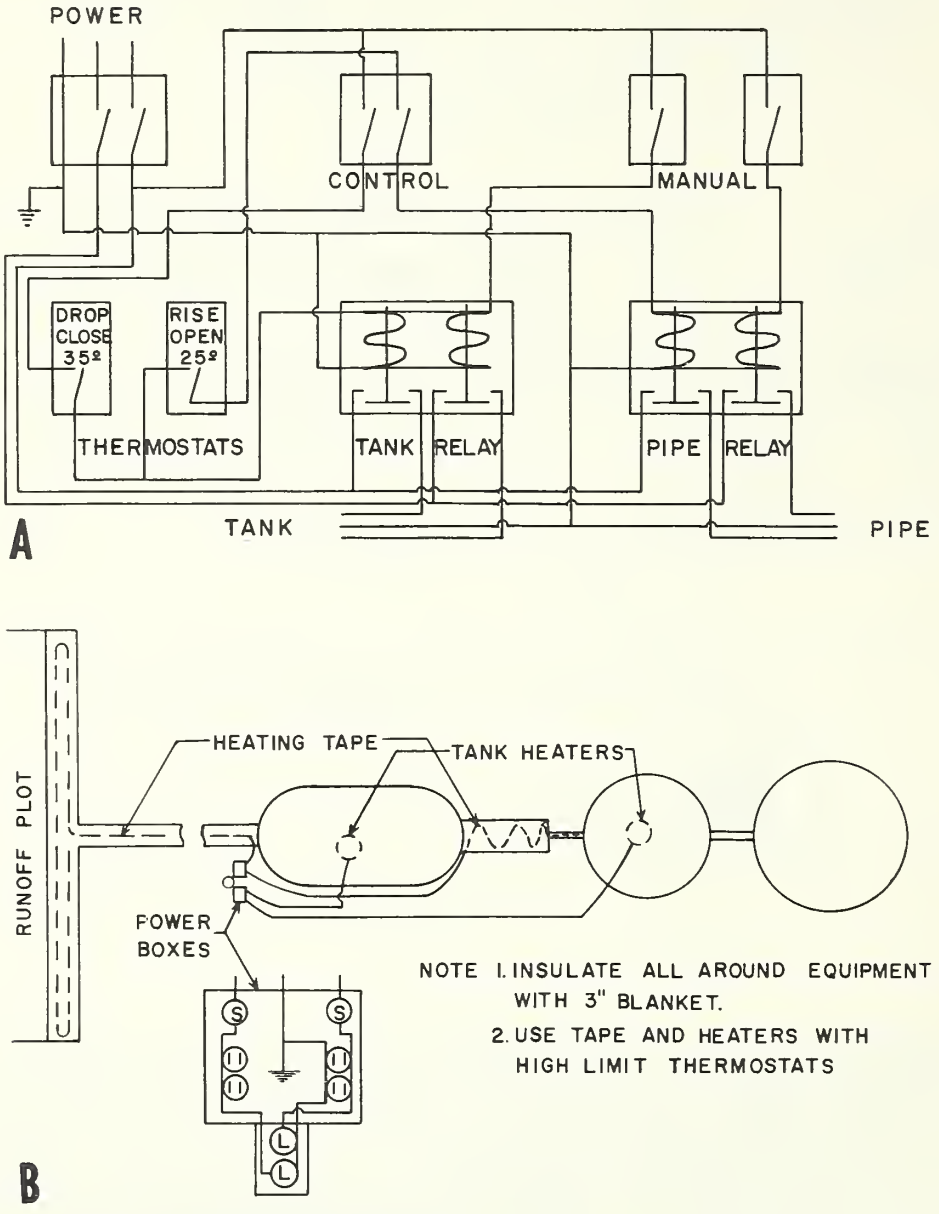


Figure 12.--A, Control board for heating equipment used for snow-melt measurement; and B, heating equipment used for snow-melt measurement.

Meteorological Measurements

The number of meteorological measurements made in conjunction with runoff plots largely depends on the specific study objectives. However, rainfall measurements are a necessity for all runoff work. A recording rain gage is required; one is sufficient if the station area is not

greater than 30 acres. Although rain gage clocks can be geared to make one revolution in 6, 12, or 24 hours or in 8 days, 24-hour gears are generally used to provide chronology with the usual once-a-day service. Often, a standard gage is placed beside the recording gage for a check on daily catch. This also eliminates the need for a place to store a measuring tube, which is used to volume rainfall in the recording gage and provide a check against catch weight as shown on the recorder chart. An excellent discussion of rain gages, their use and installation, is contained in reference (2).

Wind measurements--direction and speed--are desirable where analysis of wind effects on runoff and erosion is desired. Relative humidity and air temperatures are often taken together by readings on wet and dry bulb thermometers. Soil temperature is sometimes of interest, especially in zones of wintertime freezing temperatures.

INSTALLATION OF EQUIPMENT

The essential features of a runoff plot installation include those required for acquiring accurate data and those for convenient operation. Because of the multitude of situations, the instructions here cannot cover all cases. The installation of those critical pieces of equipment is explained and such things as steps and seeding on slopes are omitted entirely.

Several special cases need mention here. Frost-heaving is a problem in areas where freezing occurs. This requires joints between major equipment items to allow shifting without major damage. Where snow-melt measurements are not to be made, these joints are opened over the winter.

Annual elevation measurements should be made to check alinement of the various pieces of the unit and to maintain the runoff plot slope.

Boundaries

The corrugated sheet metal boundaries are easily pounded into the ground on cultivated plots. For easier installation in pasture or sod plots they should be installed when the soil is wet. A jig made up of two planks spaced apart the depth of the corrugations will keep the boundary alined during installation. After several years' use, the sheet metal boundaries may have to be re-corrugated.

The smooth galvanized metal strips are installed in essentially the same manner as the corrugated strips. If dike boundaries are desired, they can be made with a turnplow by turning two furrows in toward the plot leaving a ridge on the plot edge and a shallow channel around the plot.

Permanent plot corner markers are essential when boundaries have to be removed for primary tillage of cultivated plots.

Collector Unit

The end plate should be installed in a trench wide enough that tamping can be done from both sides. According to the condition of the soil, some driving may be done but no more than an inch or two of driving is recommended, since sheet metal is easily deformed. Roofing cement is used to seal any seams when bolting together the pieces of the unit.

Care should be taken so that the only part of the unit touching the ground is the end plate. If the collector trough rests on the ground, frost-heaving will lift the entire unit.

Pipe Lengths

Keeping excavation to a minimum is always desirable. Therefore, depending on downslope conditions, conveyance pipe lengths may be varied to allow the placing of tanks nearer the ground surface. As an example, if a minimum pipe slope was 2-1/2 percent (see section on Sediment Conveyance) and the ground slope below the runoff plot was 10 percent, the tanks could be 0.75 foot nearer to the surface for every additional 10-foot length of pipe used.

Flumes

The flumes are easily leveled and supported by two legs, as shown in figure 13. A piece of steel plate welded to the bottom of the leg is sufficient to maintain stability under most conditions. Frost-heaving and settlement are difficult to deal with. Hence, the usual solution is to check the flume level several times each year.

The flume should be so installed that the floor is level in all directions. A flume pit should be excavated deep enough to allow ease in adjusting and servicing. Shelter can be given either by enclosing the recorder and float well or by constructing a small building around the entire flume installation.

Storage and Divisor Unit

Servicing the runoff plots is always a wet, muddy job, since it occurs after a rain. Also, most of the runoff is wasted from the divisor between the tanks. Therefore, the tanks should be on a platform to allow men to sample runoff and clean the equipment without wading around in mud.

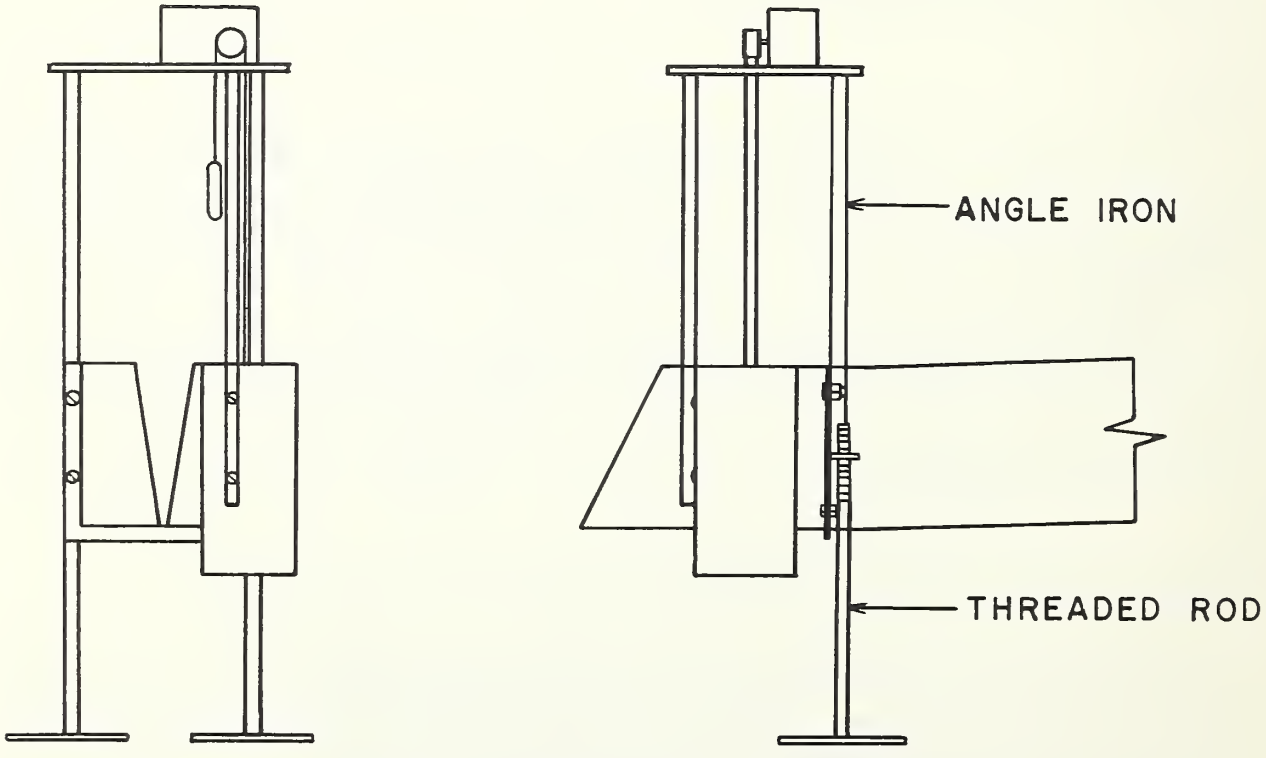


Figure 13.--Flume and recorder supports.

As shown in figures 3 and 4, slatted floors are made of treated 2- by 6-inch lumber. The platforms are supported on piles 6 to 8 inches in diameter and deep enough to reach firm footing, which is usually 2 to 3 feet.

The divisor unit functions with the floor level and the precision strip level. It should be bolted to the sludge tank in a semipermanent manner and positioned so that the top of the entrance box is level with the bottom of the inlet pipe (see fig. 11). An adjustable support approximately under the precision strip of the divisor will allow adjustment for leveling and prevention of frost-heaving damage (see fig. 9). A rectangular pipe between the divisor and the first aliquot tank carries the aliquot and also furnishes a device to adjust for small elevation errors in construction of the platforms.

The first and second aliquot tanks can be connected with a short piece of plastic pipe. Pipe-size calculation follows from the formula

$$\underline{Q} = \underline{C_d}\underline{A}\sqrt{2\,\underline{g}\underline{H}} \qquad (10)$$

Flow rate ($\underline{Q}$) is the estimated maximum runoff rate times the sampler ratio. Discharge coefficient ($\underline{C_d}$) can be taken as 0.50, which includes a factor allowing for flow resistance of the short pipe. Total head ($\underline{H}$) is figured large enough to prevent flooding the tank entrance. Area ($\underline{A}$) of the pipe cross-section is determined by the above equation. For example,

$$\underline{Q} = \text{design } \underline{Q} \times \text{divisor ratio}$$

$$= 0.2 \times \frac{1}{7} = 0.03 \text{ c.f.s.}$$

Choose $\underline{H} = 0.2$ ft.

$$\text{Then } \underline{A} = \frac{0.03}{0.5\sqrt{2 \times 32.2 \times 0.2}} = 0.017 \text{ ft.}^2$$

and pipe size is 0.147-ft. diameter, or 2-inch pipe.

All equipment connections should allow field setup. These usually involve flanges or pipe clamps with the joints sealed with roofing cement.

Site Preparation and Drainage

The downslope topography dictates the excavation and type of drainage required for the equipment. In general, the best situation is where slope is sufficient to place tanks close to the surface and use ditches to drain away runoff waste. This is by far the most foolproof type of installation. The other extreme is where the slope flattens out below the plots. For this situation, pits must be dug and drainage obtained through the use of drains. Figure 14 illustrates these two extreme situations for isolated plots.

Experiments often are laid out in blocks so that plots are separated only by border rows. Hence, excavation for the equipment can be in the form of one large ditch to accommodate equipment for all the plots. Access to the equipment with vehicles is essential. A service road

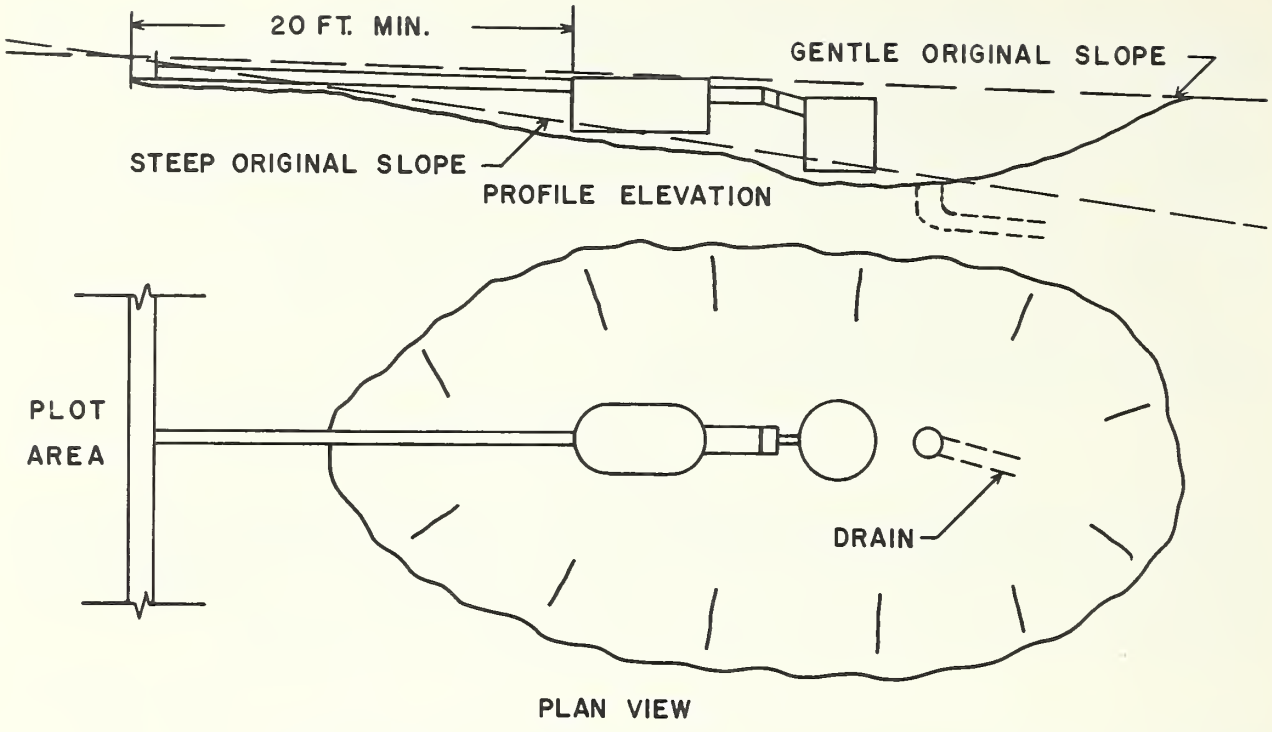


Figure 14.--Plan of site for gentle and steep slopes.

should be built to run along the line of equipment. This requires culverts or a tile drain under the road. Plans for typical installations are shown in fig. 15.

Particular note should be made for designing tile lines to carry sediment. Here again, as in conduit design, velocity should be kept above 2 feet per second. Drainage lines should be kept short and carefully maintained. Frequent inspections are necessary. Also, means to flush out sediment annually in the installation should be provided.

Installation Summary

Although a runoff plot can be designed for any site topography, the installation should be fully planned before making a site selection.

Permanent plot markers are essential. Sheet metal borders can be pounded into the ground. The collector unit, including the end plate, is positioned by the plot. Pipe slope requirements

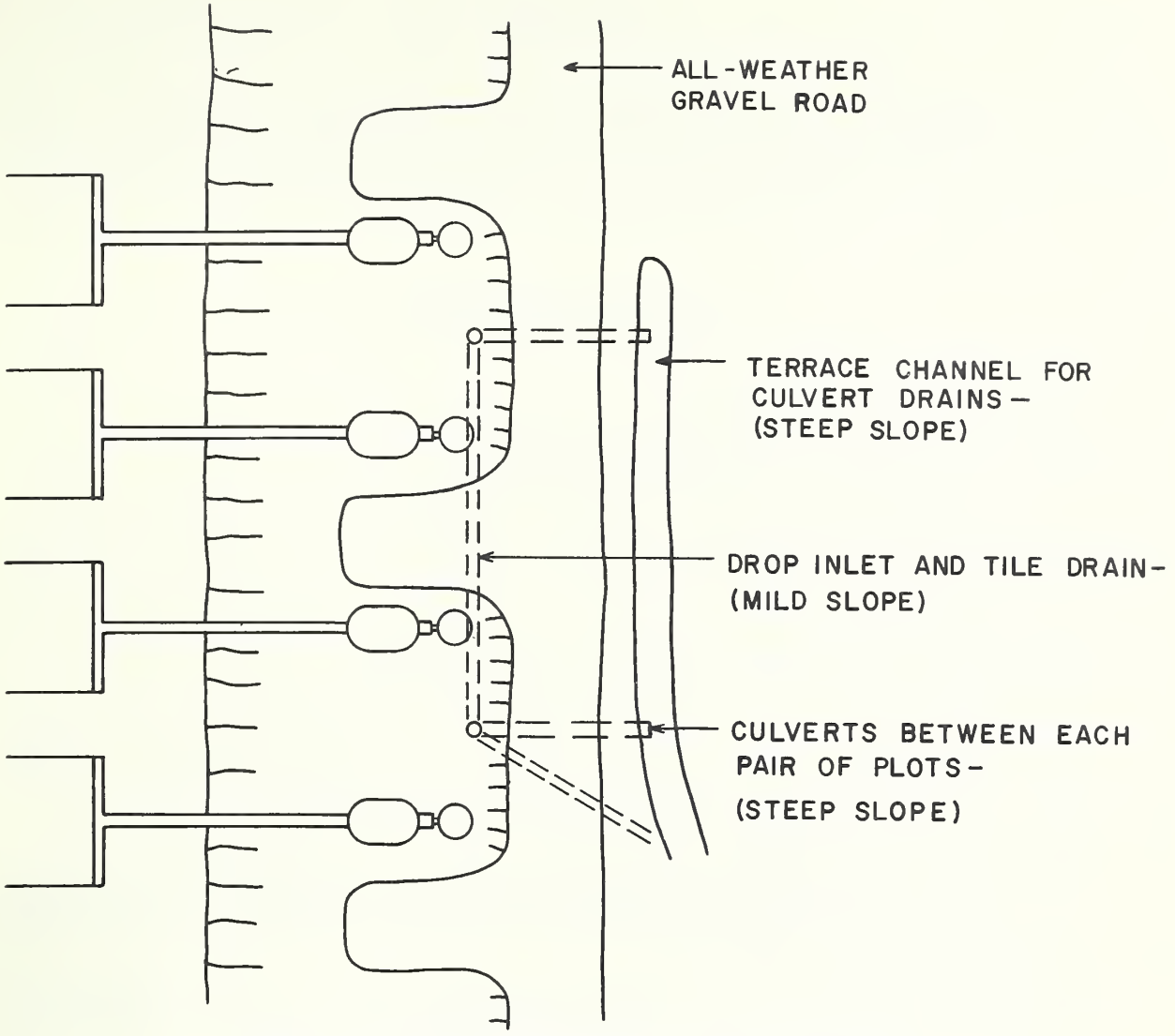


Figure 15.--Typical installation of a set of runoff plots.

are used to fix the storage and divisor unit elevation and, hence, to allow positioning to keep equipment pit excavation to a minimum.

Units should be field assembled. The connections should allow for differential elevation changes due to minor construction errors, frost-heaving, and settlement.

SUMMARY

The establishment of runoff plots begins with the selection of an area and proceeds through equipment installation. This report includes site and equipment illustrations that should afford ease in plan preparation for a specific set of erosion plots. Detailed plans are shown for the measuring device--the multislot divisor.

LITERATURE CITED

(1) Hermsmeier, L. F., and Young, R. A.
1962. Antisedimentation device for measuring flumes. Agr. Engin. 43: 648-649.
(2) Holton, H. N., Minshall, N. E., and Harrold, L. L.
1962. Field manual for research in agricultural hydrology. U.S. Dept. Agr. Agr. Handb. 224, 215 pp., illus.
(3) Meyer, L. D.
1960. Use of the rainulator for runoff plot research. Soil Sci. Soc. Amer. Proc. 24: 319-322.
(4) Parsons, D. A.
1949. Depths of overland flow. U.S. Dept. Agr., SCS-TP-82.
(5) _____
1954. Coshocton-type runoff samplers--laboratory investigations. U.S. Dept. Agr., SCS-TP-124.
(6) _____
1955. Coshocton-type runoff samplers. U.S. Dept. Agr., ARS-41-2, 10 pp.
(7) United States Weather Bureau.
1955. Rainfall intensity-duration-frequency curves for selected stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico. U.S. Dept. Com., Weather Bur. Tech. Paper 25, 53 pp., illus.
(8) Yarnell, D. L.
1935. Rainfall intensity-frequency data. U.S. Dept. Agr. Misc. Pub. 204, 67 pp., illus.

APPENDIX

Multislot Divisor

The multislot divisor is a device for taking an aliquot of runoff water. The essential part of the device is a slot plate that contains several openings or slots of identical size and shape. The runoff is passed through the divisor and that part discharged by the center slot is retained as an aliquot.

Description of Essential Parts.--

(1) Slot plate: The metal sheet containing the slots.

(2) Precision strip: The machine metal strip attached to the upstream side of the slot plate and forming the bottom of the slots.

(3) Spout: The sheet metal conduit attached to the downstream side of the slot plate that conducts the sample flow away from the middle slot.

(4) Hood: The protective sheet metal covering around the periphery of the slot plate on the downstream side.

(5) Divisor box: The sheet metal box through which the runoff water is conducted to the slot.

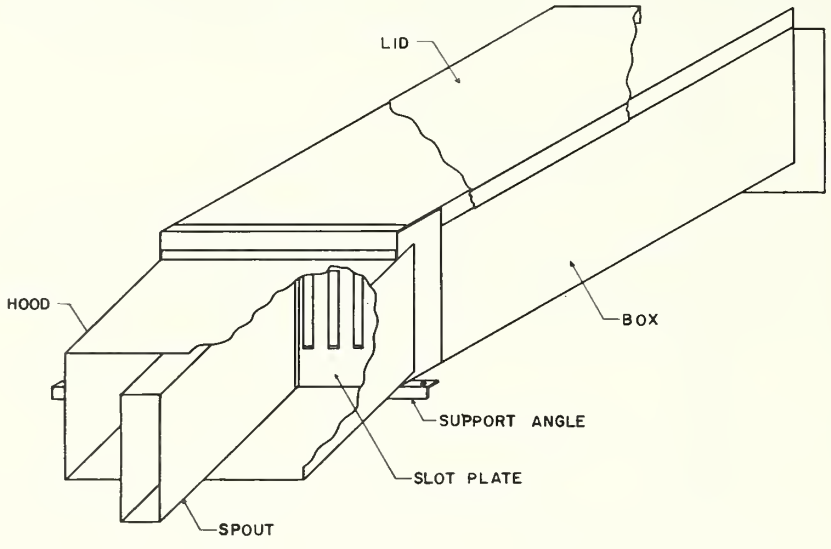
Service Requirements.--In order to obtain a sample of runoff water that is representative of the flow, the multislot divisor shall be constructed according to the accompanying plans and in accordance with the requirements and provisions supplied in any written or printed agreements to the contractor. These agreements shall specify the quantity or quality of material to be furnished for the device and the manner in which the work shall be performed.

Specifications.--To aid in size selection, a table of capacities for the multislot divisor is given. After determining the size, the attached drawing may be used as a base to prepare bid drawings. The specifications are suitable for the construction as given in the drawings.

CAPACITIES OF STANDARD MULTISLOT DIVISORS

Number of slots	Slot width	Slot height	Capacity
	Inch	Inches	c.f.s.
3	1/2	4	0.09
5	1/2	4	.15
7	1/2	4	.21
9	1/2	4	.27
11	1/2	4	.33
3	1	6	.33
5	1	6	.55
7	1	6	.77
7	1	8	1.2
9	1	8	1.5
11	1	8	1.9
13	1	8	2.2
9	1	12	2.8
11	1	12	3.4
13	1	12	4.0

CONSTRUCTION DETAILS FOR THE MULTISLOT DIVISOR

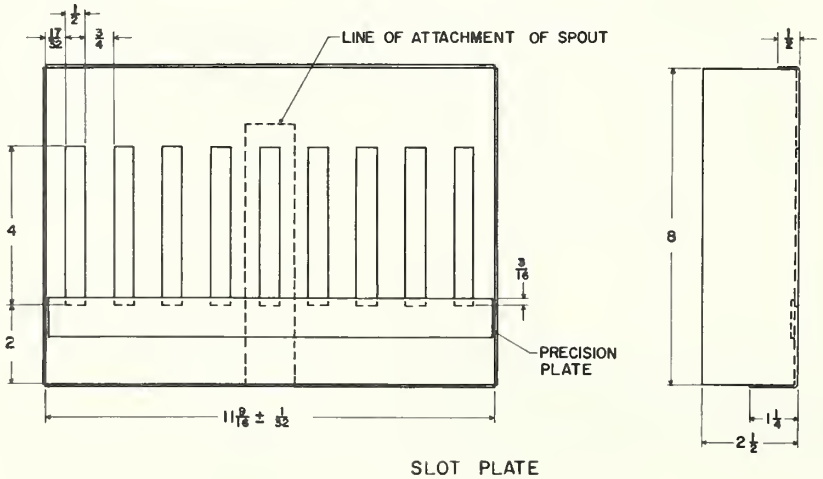


NOTES

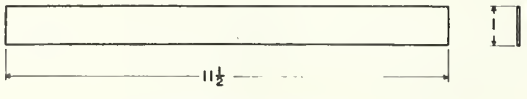
1. ASSEMBLE BY SPOTWELDING.
2. ATTACH ANGLE TO SLOT-PLATE AND BOX WITH 3 RIVETS EQUALLY SPACED.
3. SOLDER SEAMS WATERTIGHT-UNIT TO CONVEY WATER WITHOUT LEAKING – SCRAPE INSIDE SEAMS SMOOTH.

MULTISLOT DIVISOR
SWC – ARS – USDA
MAY 1961 C.K.M.

SHEET 1 OF 4



SLOT PLATE



PRECISION PLATE

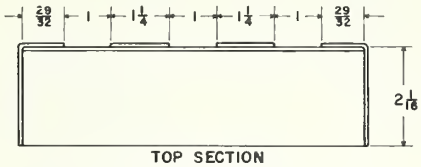
NOTES

1. MATERIALS – 16 GAUGE STAINLESS STEEL.
2. MAKE SLOT PLATE FROM SINGLE PIECE – BEND AFTER MAKING SLOTS.
3. SEE SPECIFICATIONS FOR SLOT TOLERANCES.
4. SPOTWELD PRECISION PLATE TO SLOT PLATE AS SHOWN – SEE SPEC'S FOR FURTHER REQUIRMENTS.
5. ALL DIMENSIONS ARE IN INCHES.

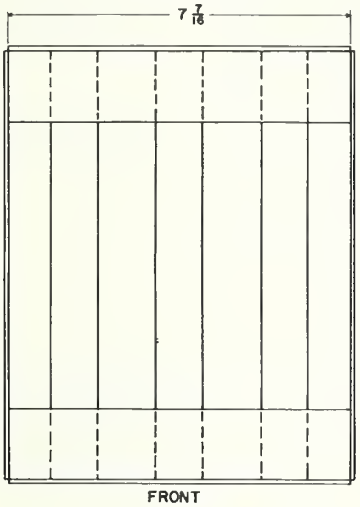
SCALE IN INCHES
0 1 2 3 4 5

SLOT PLATE FOR
MULTISLOT DIVISOR
(1 INCH SLOT)
SWC – ARS – USDA
MAY 1961 C.K.M.

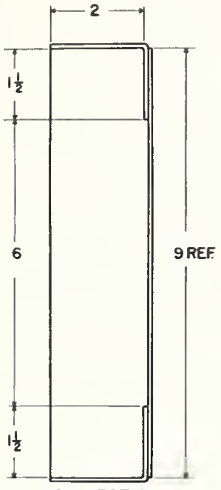
(SHEET 2A OF 4)



TOP SECTION



FRONT

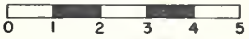


SIDE SECTION

NOTES

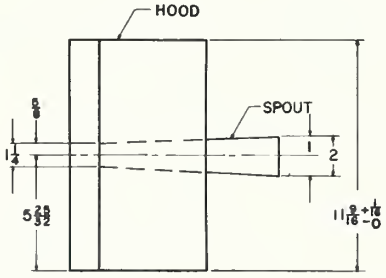
1. MATERIALS – 16 GAUGE STAINLESS STEEL.
2. ASSEMBLE BY SPOT WELDING.
3. ALL DIMENSIONS ARE IN INCHES.
4. SEE SPECIFICATIONS FOR SLOT TOLERANCES.

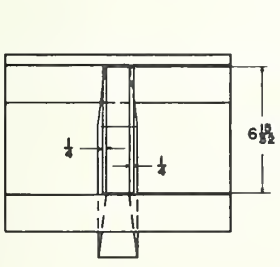
SCALE IN INCHES

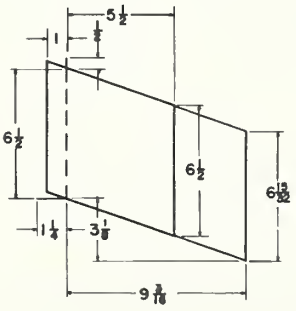


SLOT PLATE FOR MULTISLOT DIVISOR (1 INCH SLOT)
SWC – ARS – USDA
MAY 1962 C.K.M.

(SHEET 2B OF 4)



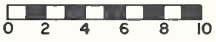




NOTES

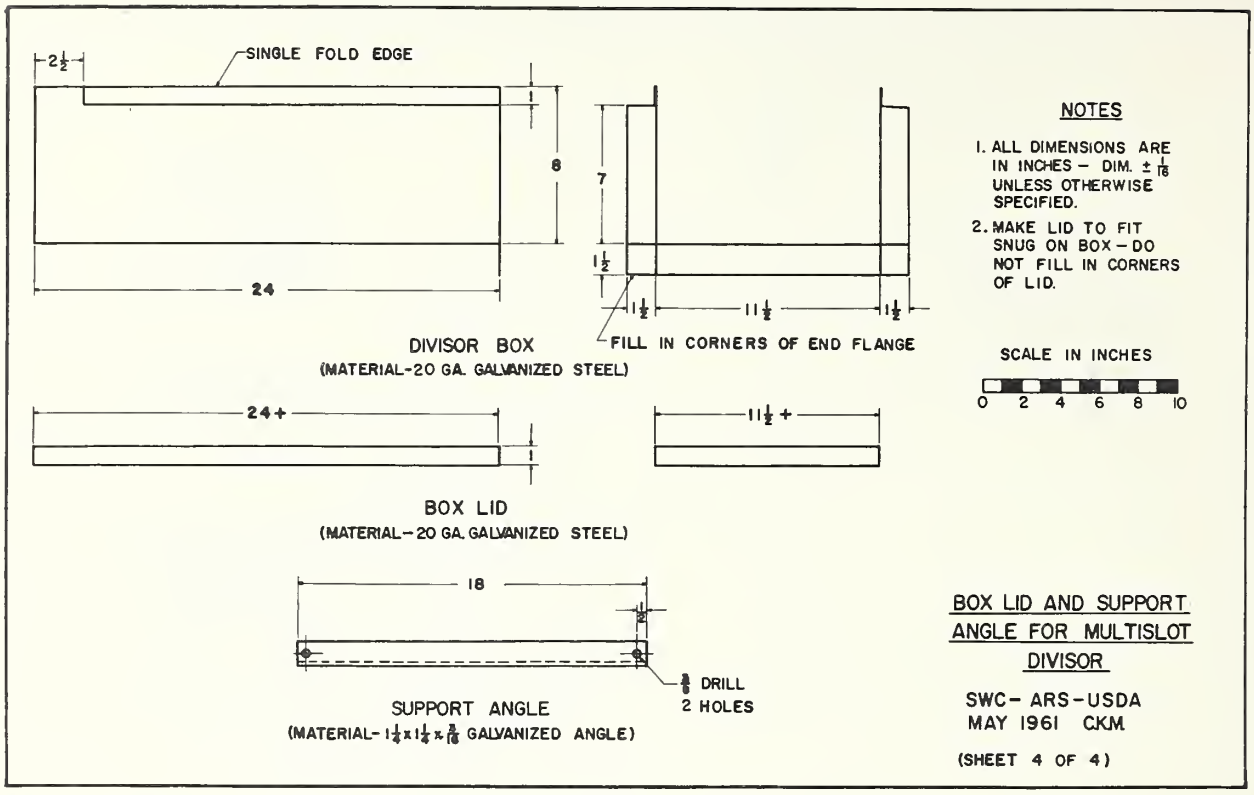
1. ALL DIMENSIONS ARE IN INCHES – DIM. ± 1/16 UNLESS OTHERWISE SPECIFIED.
2. MATERIAL – 20 GAUGE GALVANIZED STEEL.
3. ASSEMBLE BY SPOT-WELDING.

SCALE IN INCHES



SPOUT AND HOOD FOR MULTISLOT DIVISOR
SWC-ARS – USDA
MAY 1961 C.K.M.

(SHEET 3 OF 4)



As entrance conditions are quite critical, an entrance arrangement is included (fig. 16). This entrance is necessary for accurate sediment sampling.

Material for divisor with 1/2-inch slots.--Use rust-resistant material for all surfaces. The slot plate and the precision strip shall be of No. 16 gage stainless steel. The divisor box, spout, hood, and lid shall be of No. 20 gage commercial galvanized sheet iron.

Details of Construction (for 1/2-inch slots in divisor).--

(1) All seams and soldered joints shall be watertight. Solder, tool marks, or other irregularities shall not be within one-half inch of the slots on the upstream side of the slot plate nor within three-sixteenths inch of the downstream side, except that no such irregularities shall exist within a vertical distance of three-fourths inch below the bottom of the slots.

(2) The surface of the slot plate enclosing the slots and including all thereof within one-half inch of any slot shall not deviate from a plane by more than one-fiftieth inch.

(3) The slots shall be square edged. They shall be 4 inches high within one-fiftieth inch and one-half inch wide within five one-thousandths inch.

(4) The slots shall be spaced three-fourths inch apart and shall not deviate more than one one-hundredth inch.

(5) The precision strip shall be square edged, and the edge forming the bottom of the slots shall not deviate from a straight edge by more than five one-thousandths inch.

(6) The precision strip shall be electrically spot welded to the slot plate so its top edge forms an angle with the vertical sides of the slots of 90° within 10 minutes and so that all slot openings are 3-13/16 inches high within one-hundredth inch.

(7) The line of connection between the spout and the slot plate shall not deviate from a line bisecting the spaces between the center and the adjacent slots on each side by more than one-twentieth inch. The spout shall be attached before the hood is put into place.

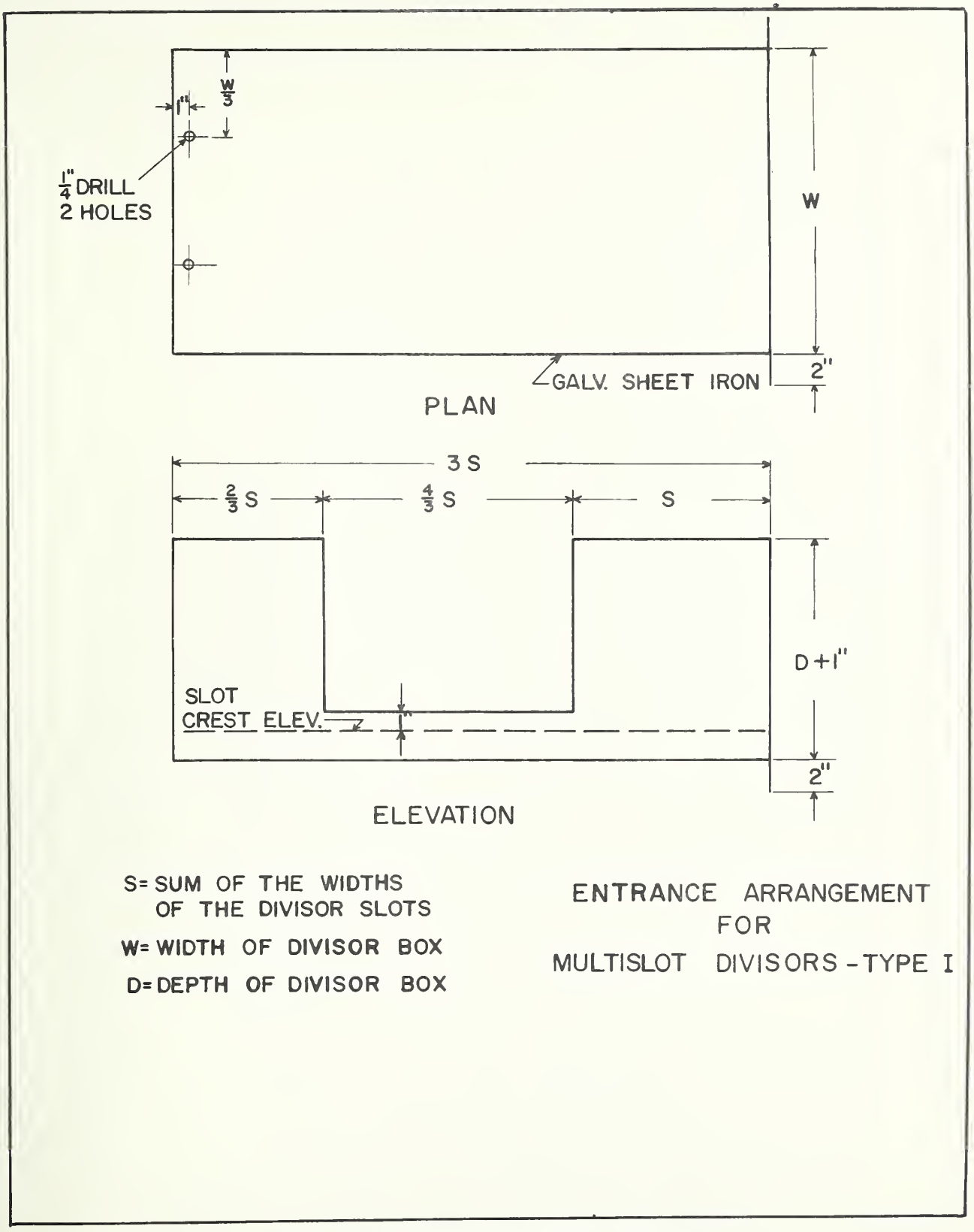


Figure 16.--Entrance for multislot divisor.